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UNUSUAL COSMIC RAY INTENSITY DECREASE OF DECEMBER 18, 1965

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ABSTRACT

Studies in the past have shown that the short term (Forbush) decrease in cosmic ray intensity recorded by a satellite borne detector ($E > 50$ MeV for protons) is about twice that registered by neutron monitors. We report here a significantly higher ratio for the decrease of December 18, 1965. This unusual value can be attributed to the depletion of low rigidity electron component which also contributes to the counting rate of the IMP III detector. Significant difference is observed in the onset times for this event recorded by the IMP III detector and the Alert neutron monitor. This can also be attributed to the differential behavior of the low rigidity electron component.

I. Introduction

Sudden decreases in cosmic ray intensity following large flares were first reported by Forbush (1938), from ionization chamber records. Typically a Forbush decrease exhibits a reduction in intensity occuring over a few hours, and a gradual recovery to about its original level in a few days. A study of the relative magnitudes of the decrease with detectors of different energy thresholds enables the determination of the rigidity dependence of the modulating process. The differences in the onset times of the decreases recorded at various stations reveal the nature of the prevailing anisotropy during the period.

Gold (1959) and Parker (1961) have suggested that extended regions of enhanced magnetic field, associated with solar flares, cause the sudden decrease in cosmic ray intensity by inhibitting the entry of energetic particles in the regions. The network of neutron monitors with high counting rates, and cosmic ray detectors on board satellites have extended to lower rigidities, the investigations of the rigidity dependence of this modulating mechanism.

Using data from Explorer VI, obtained by a detector with threshold energies of 75 MeV for protons and 13 MeV for electrons, Fan et al, (1960a) have reported that the Forbush decrease in cosmic ray intensity in interplanetary space is nearly twice that recorded by the climax neutron monitor which has a rigidity cut off of 3.06 Bv. Fan et al, (1960b) have also reported a ratio of 1.3 for the relative decreases, by a comparison of data from an identical instrument on board Pioneer V, with ground based data. Using data from Explorer XII detector, measuring protons of energy > 600 MeV, and comparing with the data from the Deep River neutron monitor, Bryant et al, (1962) obtained a ratio of 1.7 ± 0.3 for the relative decreases. Lockwood and Webber (1969) reported a ratio of 1.7 for the Forbush decrease of January 26-27, 1968, from a comparison of the intensities of protons of energy above 14 and 60 MeV registered by a detector on board Pioneer 8, and ~~that~~ recorded by the Durham neutron monitor (cut off rigidity $\sim$ 1.44 Bv). Thus from the above mentioned studies, there seems to be a general agreement among various research workers that the Forbush decrease in interplanetary space is about twice that registered by a ground based neutron monitor.

It is relevant to refer to the direct observation of interplanetary electrons of energy 3 - 12 MeV reported by Cline et al, (1964). It has also been pointed out by them that the proton intensity peaks at about 1 Bv/c and that there is negligible contribution of protons below 150 MV/c, while the electrons of rigidity $\geq$ 3.5 MV/c, are more abundant. These low rigidity particles will have smaller gyro-radii and will dominate in determining the characteristics of small Forbush decreases. The onset time of detectors, responding to both proton and electron components, like IMP-III Geiger counter, would be earlier compared to a detector responding to protons with low thresholds, like the neutron monitor at Alert (cut off rigidity < 0.5 Bv).

Balasubrahmanyan et al, (1965) have described in detail the IMP III detectors. The omnidirectional IMP-III Geiger counter, from which data is used for the present study, responds to protons of energy > 50 MeV and to electrons of energy $\geq$ 3 MeV. The contribution of the electron component has not been observed in the past studies of large Forbush decreases. The differential effect of enhanced magnetic field on this low energy low rigidity electron component is revealed in the present study of small Forbush decreases. We wish to report an example of this kind.

II. Data

A continuous record of the time history of the intensity of cosmic rays in space from May 1965 to April 1967, using the IMP-OGO satellites has already been published by Balasubrahmanyan and Venkatesan (1969). The Geiger counter (E_p > 50 MeV, $E_e \geq$ 3 MeV) has a counting rate of about 100 counts/sec. resulting in a 0.1% statistical accuracy in the daily mean hourly values. Figure 1 shows the plots of the daily means of cosmic ray intensity registered by the IMP III detector and by the Alert and Deep River neutron monitors, over the three successive solar rotations 1810, 1811 and 1812. The starting dates of each rotation are also indicated in the Figure. The Deep River neutron monitor has a cut-off of 1.02 GeV and a counting rate of about 20 x 10^5 counts/hour, while that of Alert a cut-off of < 0.05 GeV, has a counting rate of 7.2 x 10^5 counts/hour.

The event starting on December 18, 1965 is shown by a solid arrow and occurs on the 22nd day of solar rotation 1811. The recurrence of this event after 27 days is also indicated by a solid arrow. Open arrows show some of the other events which are either the 27-day recurrent type or are flare initiated ones. Minor decreases of this recurrent type have also been reported by McCracken *et al*, (1966) from Pioneer VI data. The decrease occuring on the fifth day of solar rotations 1810 and 1811 is a very stable recurrent feature revealed in all solar rotations from solar rotation 1806. Again, the decrease on the 26th day of rotations 1810 and 1811 has also been seen from solar rotation 1804 onwards. Table 1 lists the relative magnitude of decreases during various events and their dates of onset during a period of about two and a half months.

During the Forbush decrease of December 18, 1965, the IMP III Geiger counter records a decrease in intensity, $\sim$ 20 times that registered by the neutron monitor at Deep River. A Forbush decrease of nearly the same magnitude has also been observed on December 18-19, by the cosmic ray detector (protons $\gtrsim$ 7.5 MeV) on board Pioneer VI, as reported by McCracken, Rao and Bukata (1966).

Seven out of the ten decreases in cosmic ray intensity registered by Alert and nine out of the ten registered by Deep River neutron monitors (shown in Table 1) are below one percent. Nevertheless they are significant on a daily basis and occur coincident with the enhanced magnetic field measurement of the magnetometer on board IMP III. Relative decreases of IMP III detector and the neutron monitor stations are statistically the same except for the December 18th and January 14th events for which the ratios of relative decreases of IMP III and Deep River are very high.

Figure 2 shows the hourly values of cosmic ray intensity recorded by various neutron monitors along with cosmic ray intensity measurements from IMP III and Pioneer spacecraft and the magnetometer data from IMP III. Hourly values of the magnetic parameter D_{st}, published by Sugiura and Cain (1970) have also been included in the Figure. IMP III magnetometer fluctuates between two and four gammas up to 0500 UT on December 18th, then starts to increase and attains a value of 11 gammas at 1000 UT. From 1100 UT to 1500 UT it remains between 8 and 9 gammas. At 1600 UT it again reaches a value of 11 gammas. It reverts back to the quiet time value of four gammas within eleven hours. The total duration for the enhancement of the magnetic field lasts for about twenty-four hours. Nearly identical enhancement of the magnetic field was also reported by Ness (1966) from the data of the magnetometer on board Pioneer VI about 500,000 km away from the IMP III satellite.

Coincident with the rise of the strength of the magnetic field, both the IMP III and Pioneer VI detectors register the onset of a Forbush decrease. The Inuvik (cut-off of 0.18 BV) and Deep River neutron monitors do not reveal any Forbush decrease in intensity, but do show some significant fluctuations during the period. The Alert neutron monitor which responds to much lower rigidity particles arriving from polar direction does indeed exhibit a Forbush decrease. The onset of the first major decrease in the Alert monitor occurs about seven hours after both the satellite detectors record the decrease. Note further that the Pioneer VI data show an increase in intensity for about 17 hours before the onset of the Forbush decrease. IMP III detector does not show a corresponding increase but shows less fluctuations in intensity during this interval. Both the satellite detectors exhibit a two-step decrease in intensity, the first one being time coincident with the sudden increase in magnetic field strength at 0900 UT on December 18, and the second one with the decrease in intensity recorded by the Alert neutron monitor as well as the major decrease in the magnetic parameter D_{st}.

III. Discussion

It is clearly seen from Figure 2 and Table 1 that both IMP III and Pioneer VI recorded significantly a larger Forbush decrease during the December 18-19 period in comparison with that registered by the Deep River neutron monitor. Twenty-seven days later both the satellite detectors again show very similar larger decrease compared to that of Deep River, exhibitting the quasi-periodic recurrence. In the absence of any solar flare activity and in view of the observed 27-day recurrence, the Forbush decrease must be attributed to a co-rotating shock front rather than to any flare-initiated blast wave. This agrees with the findings of McCracken et al, (1966). The modulation of galactic cosmic rays, according to them, arises from a standing corotating shock front with a sharp boundary, inhibitting diffusion of cosmic rays across this boundary. The onset time of the Forbush decrease reveals the boundary. It is relevant to point out that the boundary corresponding to the depletion of low rigidity particles and hence with smaller gyro-radii would be observed earlier than that due to depletion of relatively higher rigidity particles. In fact, the present observation does confirm this point of view, by revealing an earlier onset time at IMP III than at Alert. It is not possible to ascribe that the higher decrease at the satellite detectors relate entirely to the lower energy particle contribution to the satellite detectors, since several other events are cited in Table 1, where the ratios of decreases in intensity measured in space to those registered in the ground based detector are not unusually high as in the December event. The high value for the ratio for this event can be attributed to the depletion of low rigidity electron component which contributes to the intensity recorded by the IMP III detector. Figure 3 shows the daily means of intensity recorded by the IMP III detector along with the interplanetary electron data (Private Communication, T. Cline, 1971) recorded on the same satellite. Note that the observed electron intensity decreases significantly and simultaneously on December 19. One expects the depletion of the electron component would contribute significantly only in the small Forbush decreases, which are primarily low energy phenomena, where higher energy proton component is not significantly depleted as is evident from ground based neutron monitor data. This could occur when the region of the enhanced magnetic field, because of its limited spatial extent could deplete low rigidity particles preferentially. The magnetic field enhancement, related to this event, lasts for about twenty-four hours. On the basis of a plasma speed of 300 Km/sec, one could estimate the spatial extent of the region of enhanced magnetic field to be about 26×10^6 Km. In a magnetic field of ten gammas as recorded by IMP III magnetometer, the gyroradius of electrons in the energy range of few MeV would be small compared to the extent of the magnetic field and would be efficiently depleted from this region. Low energy protons would also be depleted, so that, a station like Alert whose cut-off is 0.05 BV could register a Forbush decrease. As mentioned earlier the corotating shock would be first registered as the onset of the Forbush decrease by the low rigidity electron component, while the higher rigidity protons with larger gyroradii would show a later onset.

Note that, 27 days later, on January 14, 1966 the ratio of decrease in intensity observed at satellite detectors to that registered by the neutron monitors at Deep River is again very high. It is interesting to note that on January 14th the enhancement of the magnetic field as recorded by IMP magnetometer lasts for only a couple of hours, which substantiates the argument that a region of enhanced magnetic field, limited in extent can only deplete low energy particles.

IV. Conclusion

The present study shows that there are instances when the relative decrease of cosmic ray intensity as recorded by IMP III detector to that registered by ground based neutron monitor, could be as high as 20, which is significantly different from the usual reported value of ~ 2.

From this, it appears that the study of rigidity dependence of modulation processes from the study of relative decreases of space borne equipment and ground based detectors, needs careful evaluation.

It is not possible to attribute this to the lower threshold of the satellite detectors, since all decreases do not exhibit this high value for the ratio. A reasonable suggestion is to attribute the unusual ratio to the behaviour of the electron component which also contributes to the intensity recorded by the IMP III detector and the Alert neutron monitor also can be explained on the basis of the differential behaviour of the electron component.

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REFERENCES

Balasubrahmanyan, V.K., G.H. Ludwig, F.B. McDonald and R.A.R. Palmeira. Results from the IMP 1 G.M. counter telescope experiment. J. Geophys. Res., 70, 2005-2019, 1965.

Balasubrahmanyan, V.K., and D. Venkatesan. Spectral variation in short term (Forbush) decreases and in long term changes in cosmic ray intensity. Goddard Space Flight Center Document X-611-69-1413, pp 175-195, September 1969 and Proc. 11th Cosmic Ray Conf., Budapest, Hungary.

Bryant, D.A., T.L. Cline, U.D. Desai and F.B. McDonald. Explorer XII observations of solar cosmic rays and energetic storm particles after the solar flare of September 28, 1961. J. Geophys. Res., 67, 4983-5000,1962.

Cline, T.L., G.H. Ludwig and F.B. McDonald. Detection of Interplanetary 3 - 12 MeV electrons. Phys. Rev. Letters, 13, X5481-4 - X5484-4, 1964.

Fan, C.Y., P. Meyer and J.A. Simpson. Cosmic radiation intensity decreases observed at the earth and in the nearby planetary medium. Phys. Rev. Letters, 4, 421-423, 1960a.

Fan, C.Y., P. Meyer and J.A. Simpson. Rapid reduction of cosmic ray intensity measured in Interplanetary Space. Phys. Rev. Letters, 5, 269-271, 1960b.

Forbush, S.E., On world-wide change in cosmic ray intensity. Phys. Rev., 54, 975-988, 1938.

Gold, T., Plasma and magnetic fields in the solar system. J. Geophys. Res., 64, 1665-1674, 1959.

Lockwood, J.A., and W.R. Webber. Cosmic Ray intensity variations of January 26 - January 27, 1968. J. Geophys. Res., 74, 5599-5610, 1969.

McCracken, K.G., U.R. Rao and R.P. Bukata. Recurrent Forbush decreases associated with M-region magnetic storms. Phys. Rev. Letters, 17, 928-932, 1966.

Ness, N.F. Simultaneous measurements of interplanetary magnetic field. J. Geophys. Res., 71, 3319-3324, 1966.

Parker, E.N. Sudden expansion of the corona following a large solar flare and the attendant magnetic field and cosmic ray effects. Astrophys. J., 133, 1014-1033, 1961.

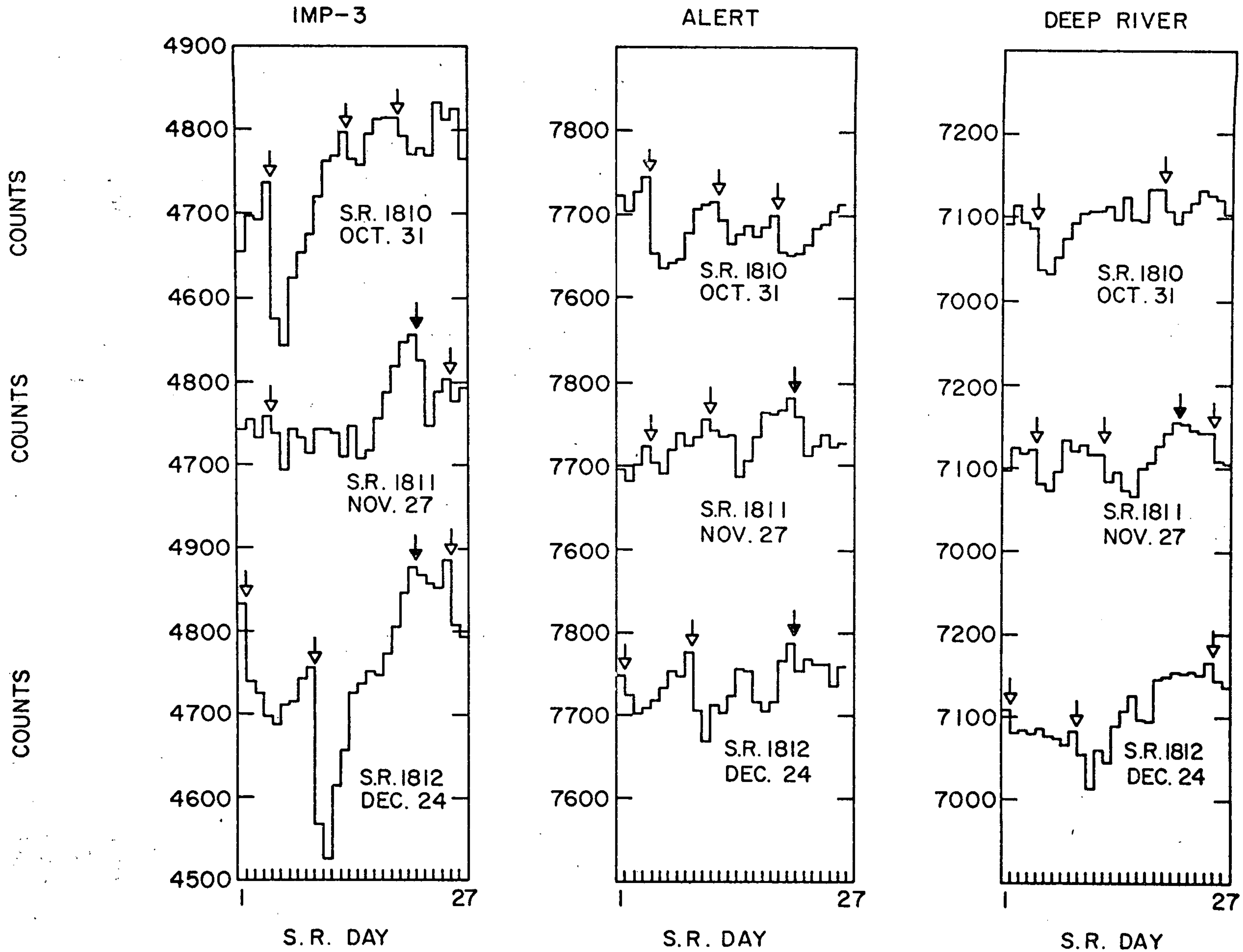
Sugiura, M., and S. Cain. Provisional hourly values of equatorial D_{st} for 1964, 1965 and 1967. NASA Tech. Note TN D-5748, May 1970.

TABLE 1

Onset Date of Decrease	IMP III Geiger Counter	Alert Neutron Monitor	Deep River Neutron Monitor	Ratio	
				IMP III / Alert	IMP III / Deep River
11/4/65	4.11% ± 0.20	1.34% ± .04	0.78% ± .02	3.07	5.27
11/13/65	0.81% ± 0.22	0.33%	0.22%	2.45	3.80
11/19/65	0.90% ± 0.23	0.58%	0.59%	1.55	1.53
12/1/65	1.34% ± 0.22	0.41%	0.68%	2.44	1.97
12/18/65	2.2% ± 0.23	0.88%	0.12%	2.50	19.18
12/22/65	0.52% ± 0.20	0.19%	0.46%	2.74	1.13
12/25/65	2.95% ± 0.20	0.73%	0.41%	4.04	7.20
1/2/66	4.8% ± 0.20	1.35%	0.95%	3.56	5.05
1/14/66	0.52% ± 0.20	0.32%	0.03%	1.63	17.33
1/18/66	4.42% ± 0.23	1.61%	1.37%	2.75	3.23

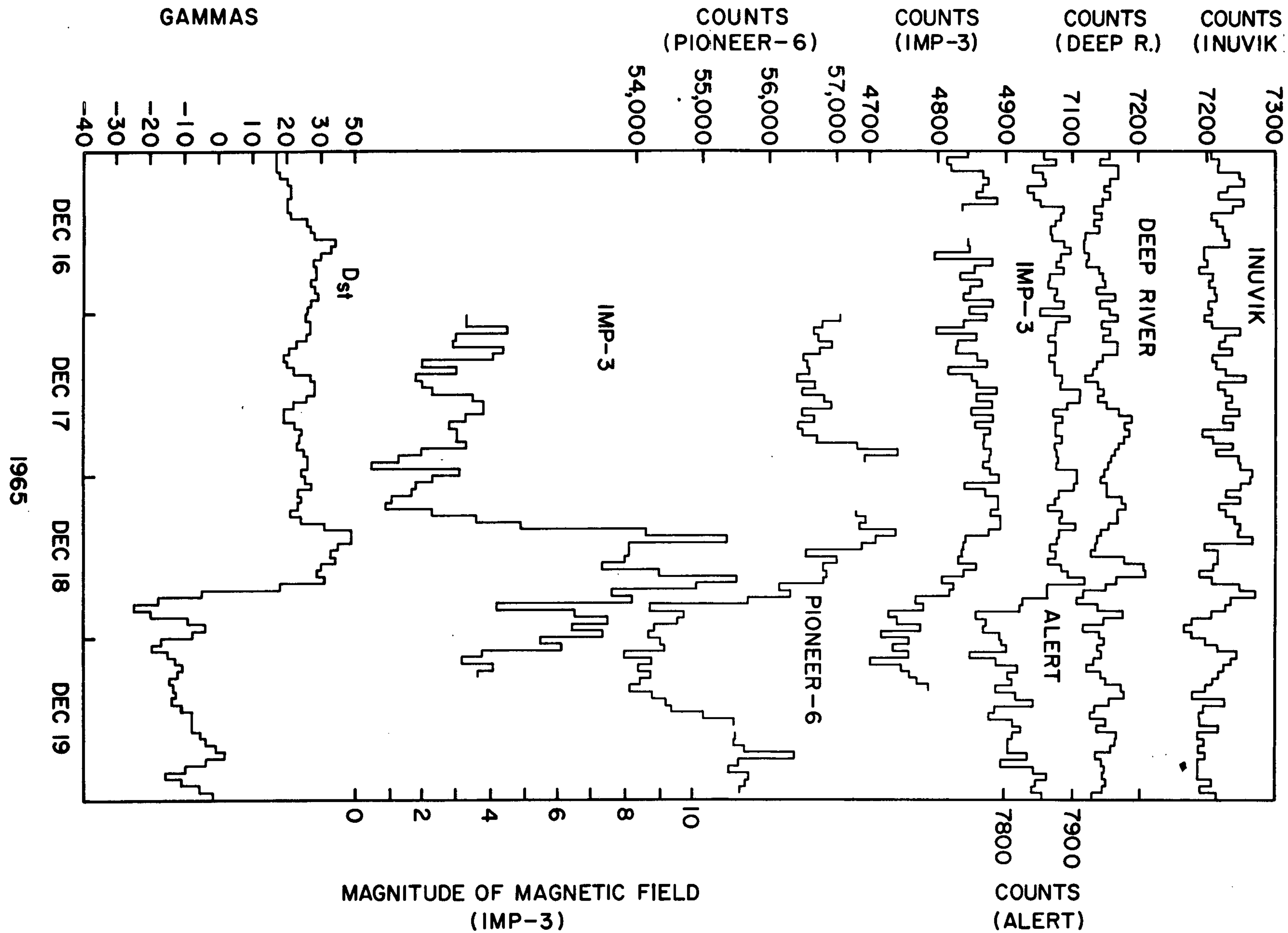
Intensities recorded by IMP III detector and Alert and Deep River neutron monitors, along with ratio of the intensities recorded in space to that registered on ground level, for a number of decreases.

LIST OF FIGURES



IMP-3
ALERT
DEEP RIVER
COUNTS
COUNTS
COUNTS
4900
4800
4700
4600
4800
4700
4900
4800
4700
4600
4500
S.R. 1810
OCT. 31
S.R. 1811
NOV. 27
S.R. 1812
DEC. 24
7800
7700
7600
7800
7700
7600
7800
7700
7600
7200
7100
7000
7200
7100
7000
7200
7100
7000
1
27
S.R. DAY
S.R. DAY
S.R. DAY

FIGURE 1



GAMMAS
COUNTS (PIONEER-6)
COUNTS (IMP-3)
COUNTS (DEEP R.)
COUNTS (INUVIK)
-40 -30 -20 -10 0 10 20 30 50
54,000 55,000 56,000 57,000
4700 4800 4900
7100 7200
7200 7300
INUVIK
DEEP RIVER
IMP-3
Dst
IMP-3
PIONEER-6
ALERT
DEC 16
DEC 17
DEC 18
DEC 19
1965
0 2 4 6 8 10
7800 7900
MAGNITUDE OF MAGNETIC FIELD (IMP-3)
COUNTS (ALERT)

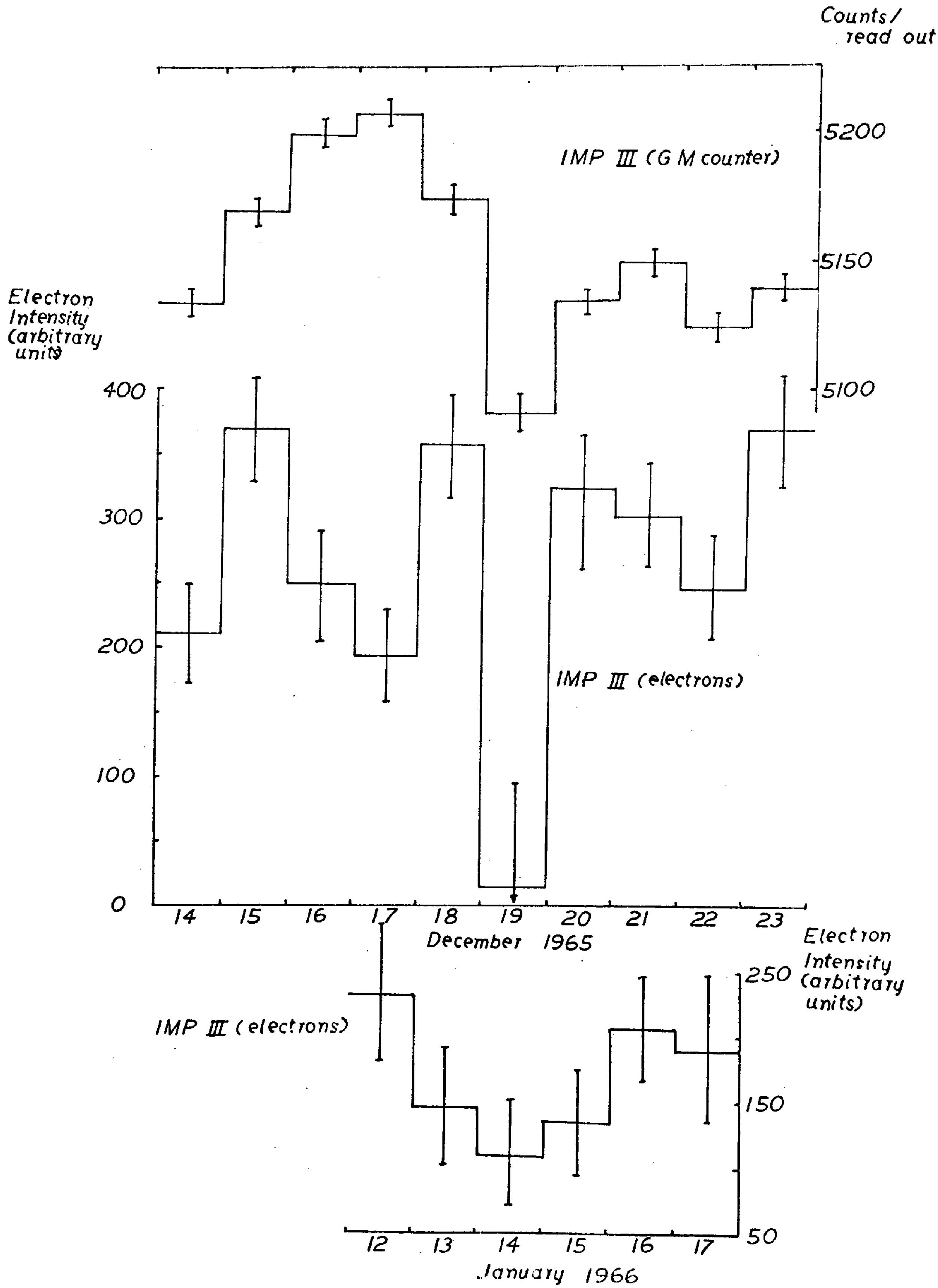

Counts/
read out
5200
5150
5100
IMP III (G M counter)
Electron
Intensity
(arbitrary
units)
400
300
200
100
0
IMP III (electrons)
14
15
16
17
18
19
20
21
22
23
December 1965
Electron
Intensity
(arbitrary
units)
250
150
50
IMP III (electrons)
12
13
14
15
16
17
January 1966

FIGURE 3